Surface Atmosphere Radiation Budget (SARB) working group update

Seiji Kato[1], Fred G. Rose[2], David A. Rutan[2],

Alexander Radkevich[2], Thomas E. Caldwell[2],

Antonio Viudez-Mora[2], Seung Hee Ham[2],

David Fillmore[3], Xianglei Huang[4], and Tyler J. Thorsen[1]

[1]NASA Langley Research Center

[2]Science System & Applications Inc.

[3]Tech-X

[4]University of Michigan

CERES Science team meeting

September 26-28, 2017

Goddard Space Flight Center, Greenbelt, MD

Work done after the last CERES meeting

- Released Edition 4.0 EBAF-surface from March 2000 through August 2016
  - Submitted Ed4.0 EBAF-surface paper
- Extended Edition 2.8 EBAF-surface through December 2016
- Released Edition 4.0 SYN1deg-Month, -day, -Hour
- Evaluation of Edition 4.0 EBAF-surface and SYN1deg
  - Surface validation
  - Heating rates evaluation
  - Entropy production estimates

Available data products

- Ed 4 SYN (Terra + Aqua)
  - March 2000 through February 2017
- Ed 3 SYN
  - March 2000 through February 2017
- Ed4 EBAF-surface
  - March 2000 through August 2016
  - Waiting for Himawari 8 (Himawari 8 is used since July 2015)
- Ed2.8 EBAF-surface
  - March 2000 through December 2016
  - Will be processed through February 2017
  - AIRS product AIRX3STM.006 is used through August 2016 and AIRS3STM.006 starting September 2016 (due to the AMSU-A2 issue).
- Ed1 SYN (Terra + NPP)
  - Data has not been released yet
- C3M (with version 3 CALIPSO and ed? CloudSat)

MODIS and GEO issues/solutions

- MODIS collection 5
  - Is used for Ed4 SYN through February 2017.
  - Is used for Ed4 EBAF-surface through August 2016 and will be used through February 2017.
  - Nighttime polar downward longwave is corrected by a time dependent correction starting March 2016.
- MODIS Collection 6
  - Will be used for Ed4 SYN and EBAF-surface from March 2017 onward.
  - Terra water vapor channel is turned off.
- MODIS collection 6.1
  - Ed4 SYN will be reprocessed starting March 2016.
- Himawari 8
  - Clouds are processed with misaligned pixels (from July 2015 through August 2016).
  - Clouds are processed with the correct month of MATCH aerosols (not climatology). All other GEOs are processed without MATCH aerosols.
- MET8
  - starts providing cloud properties over Indian ocean with the Version 0 cloud algorithm from December 2016

Outline of this talk

- SYN1deg product
  - Hourly mean surface irradiance uncertainty
  - Heating rate evaluation
  - Entropy production estimate
  - MATCH aerosols
- Snow BRDF model

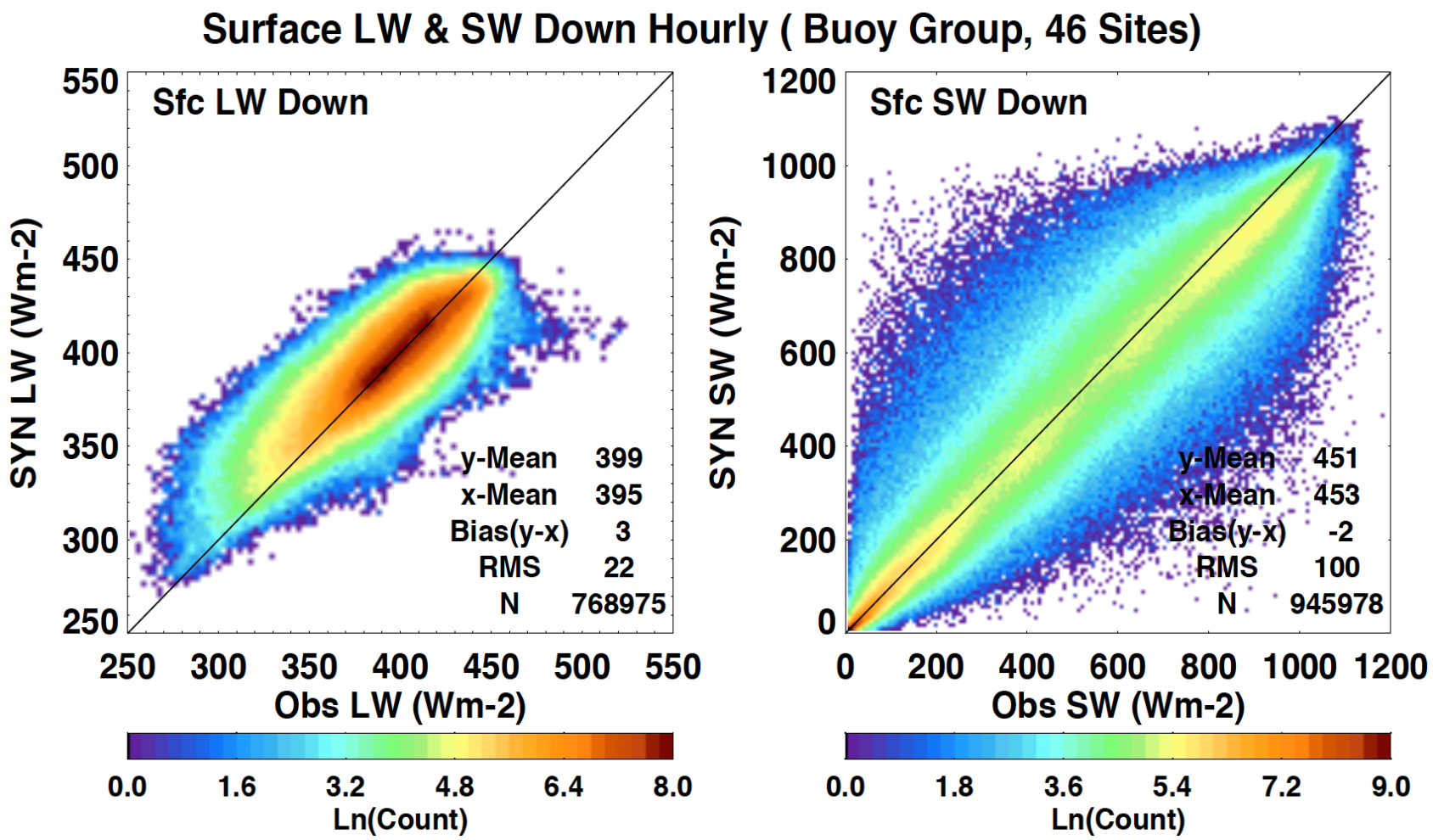
SYN1deg data products

- Contains
  - Observed TOA irradiance (hourly, daily, and monthly gridded mean).
  - Computed TOA and surface irradiances (hourly, daily, and monthly gridded mean).
  - Computed in atmosphere irradiances at 70, 200, 500, and 850 hPa levels.
  - All-sky, clear-sky, pristine (no clouds, no aerosols), and all-sky no aerosol fluxes.
- Clear-sky irradiances are computed with removing clouds.
- Users who are interested in monthly mean irradiances need to use EBAF products.
- Due to bugs in the production code, adjusted fluxes contain errors. Users are advised not to use adjusted TOA and surface shortwave and longwave fluxes.
- Only adjusted fluxes are available for in atmosphere fluxes and surface direct and diffuse fluxes.

SARB Inputs for SYN1deg data products

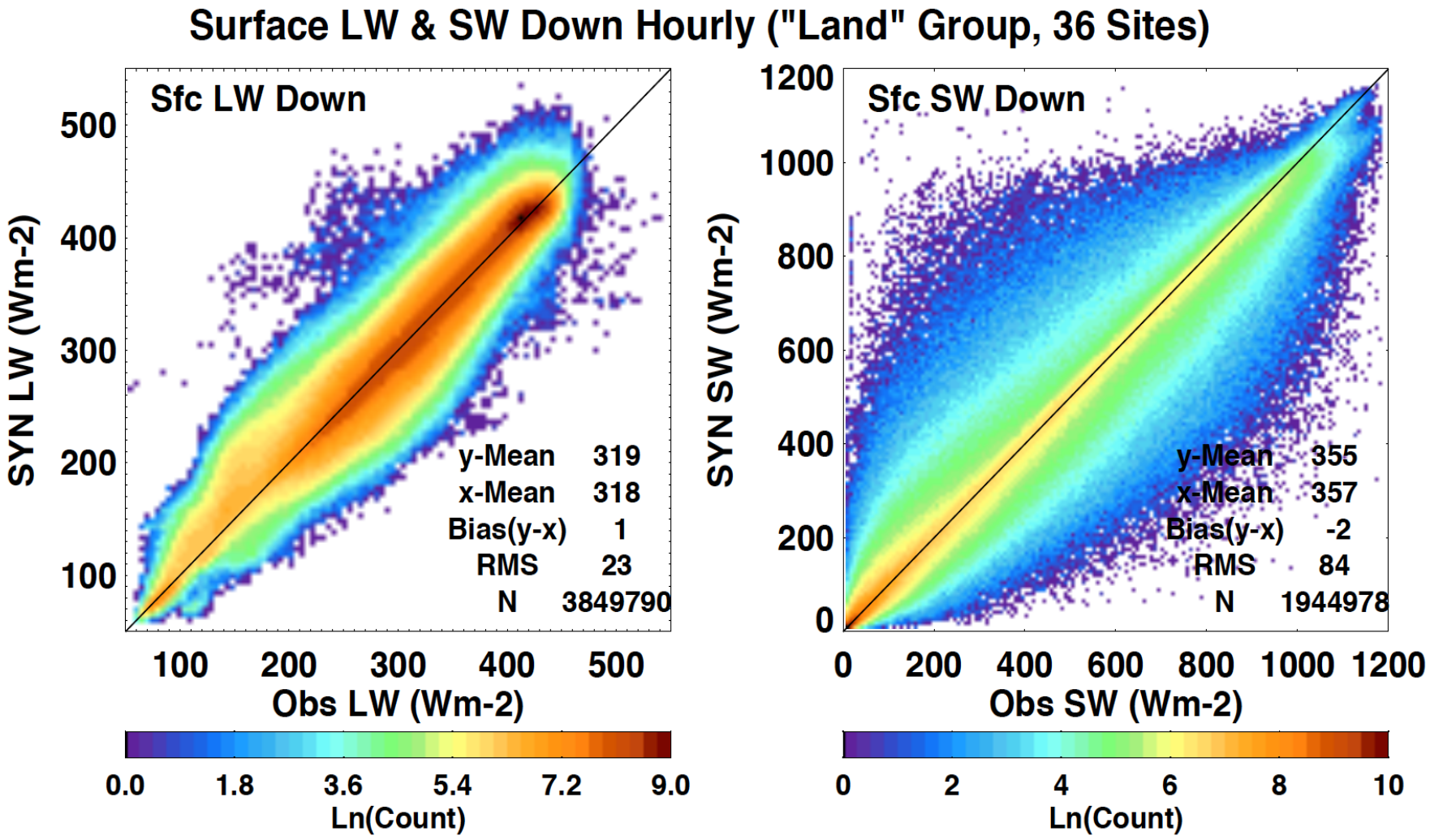
Input variable	Source	References
Cloud properties	Derived from MODIS and GEOs	Minnis et al. (2017)
Aerosols	MATCH	Collins et al.
Ocean surface albedo	Model	Jin et al. (2004)
Land surface albedo	CERES (broadband) MODIS (spectral shape)	Rutan et al. (2009)
Sea ice snow albedo	CERES (broadband), MODIS (spectral shape)	
Emissivity		Wilber et al. (1999)
Temperature	GEOS-5.4.1	
Specific humidity	GEOS-5.4.1	
Ozone	GEOS-5.4.1	
Snow and sea ice	NSIDC near-real time snow and ice extent (NISE)	
Skin temperature	MODIS, GEOs, GEOS-5.4.1	

Evaluation of hourly mean irradiance (Ocean)



RMS difference is used for or defined as the uncertainty

Evaluation of hourly mean irradiance (Land)



Hourly regional irradiance uncertainty derived from RMS differences

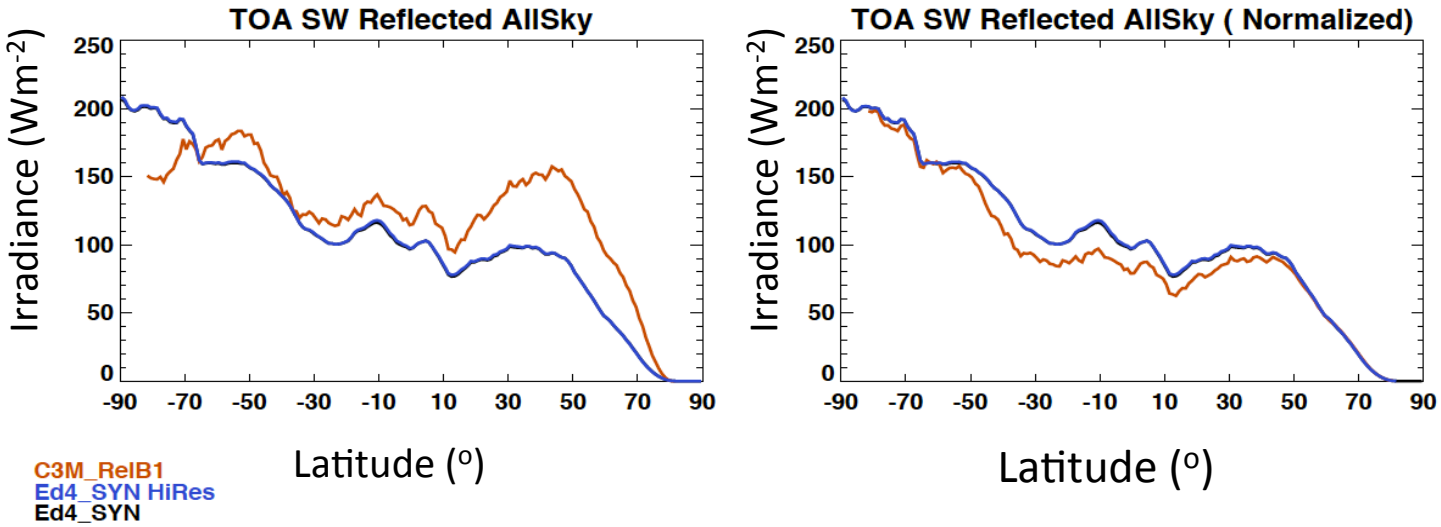
		Mean Irradiance (Wm-2)	Uncertainty (Wm-2)
Downward shortwave	Ocean + Land	187	43
	Ocean	191	42
	Land	195	46
Downward longwave	Ocean + Land	345	21
	Ocean	364	20
	Land	333	24

Evaluation of SYN heating rates

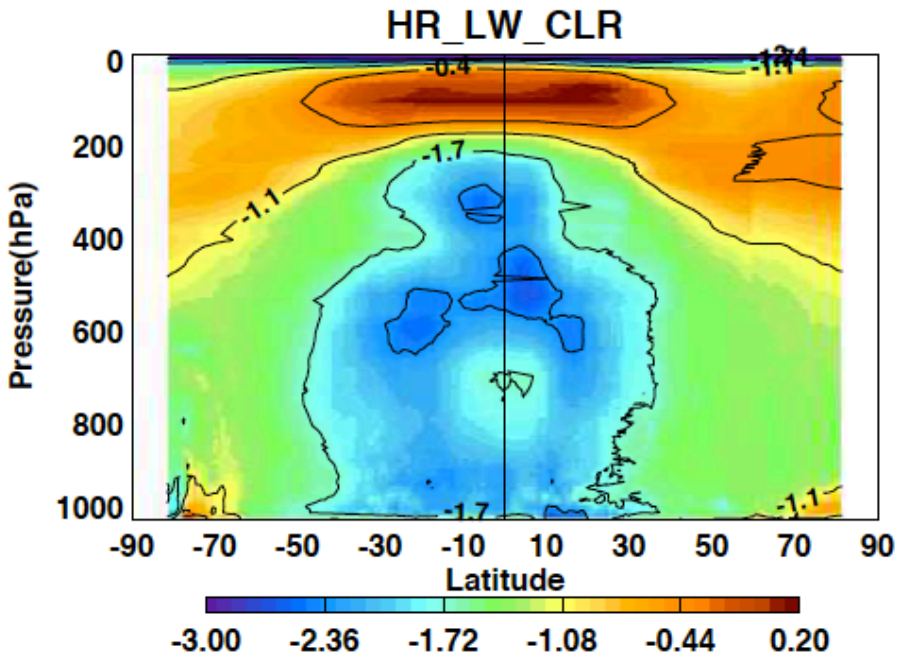
- SYN1deg includes surface irradiances and in-atmosphere irradiances at 70, 200, 500, and 850 hPa levels.
- In-atmosphere irradiances are not evaluated before.
- We output SYN1deg with a high vertical resolution (25 vertical levels)
- CCCM has heating rate profiles computed with CALIPSO and CloudSat
- CCCM has a high vertical resolution (138) but contains instantaneous heating rate (i.e. not diurnally averaged).
- We apply instantaneous to diurnal mean scaling to CCCM irradiance profiles.

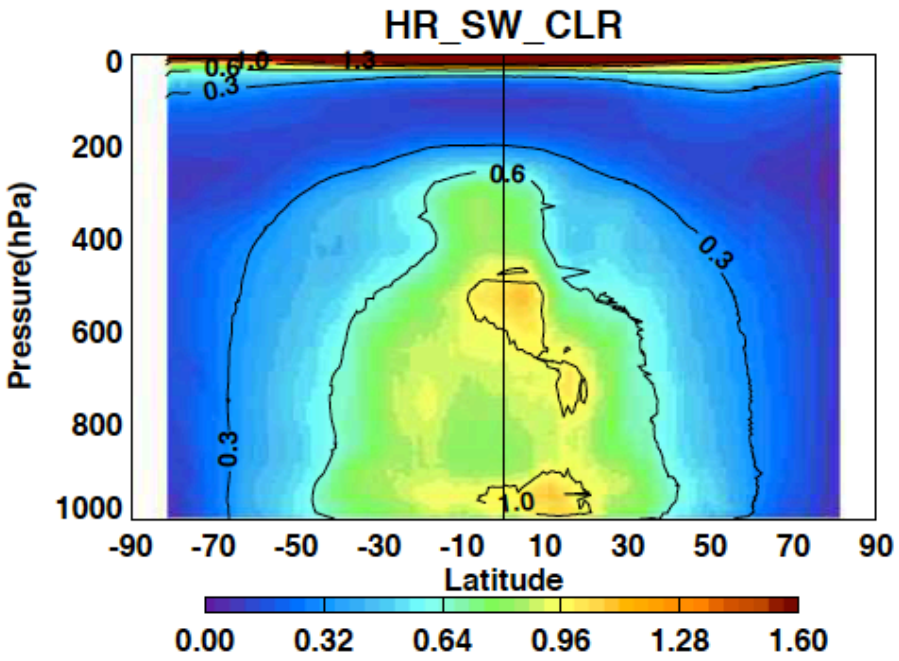
Instantaneous to diurnal mean scaling

- All levels of C3M up and downward shortwave irradiances are multiplied by the ratio of monthly gridded mean solar constant divided by the mean of instantaneous solar constant for the Aqua overpass time.
- Diurnal mean longwave is the average of daytime and nighttime longwave irradiances



Clear-sky heating rate (March 2011)





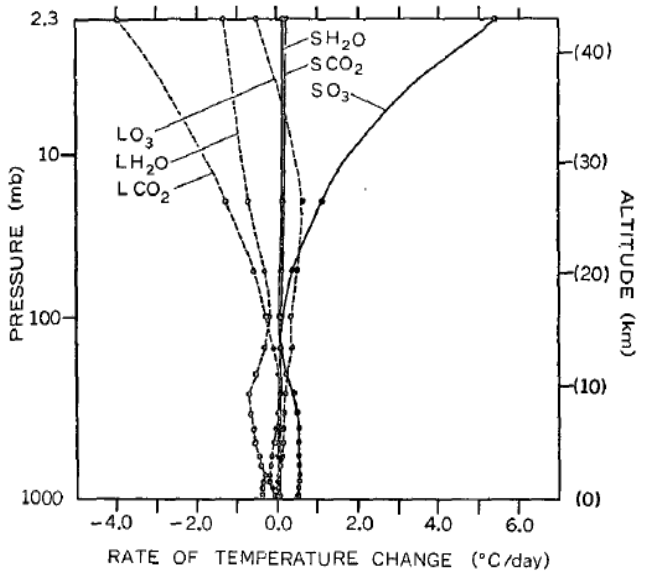
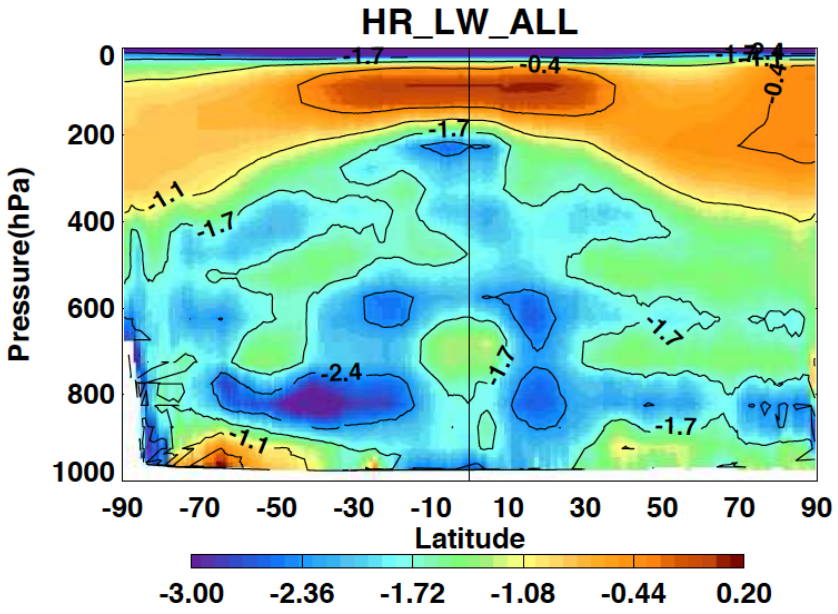


FIG. 6b. Vertical distributions of the rate of temperature change of the ($H_2O+CO_2+O_3$) atmosphere in pure radiative equilibrium due to various absorbers. LH_2O, LCO_2, and LO_3 show the rate of temperature change due to long wave radiation of water vapor, CO_2 (the effect of H_2O overlapping was included), and O_3. SH_2O, SCO_2, and SO_3 show the rate of temperature change due to the absorption of solar radiation by water vapor, CO_2, and O_3.

(Manabe and Strickler 1964)

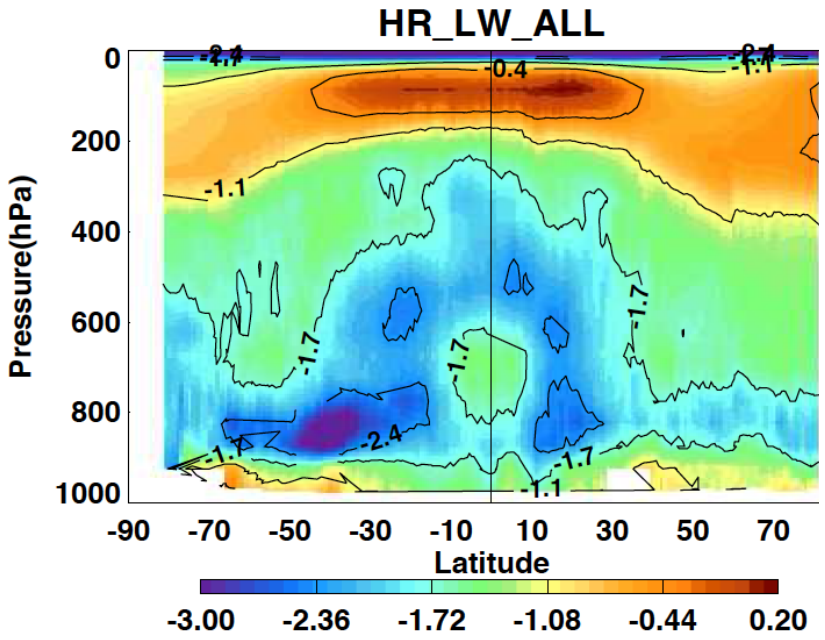
Longwave heating rate March 2011

SYN1deg



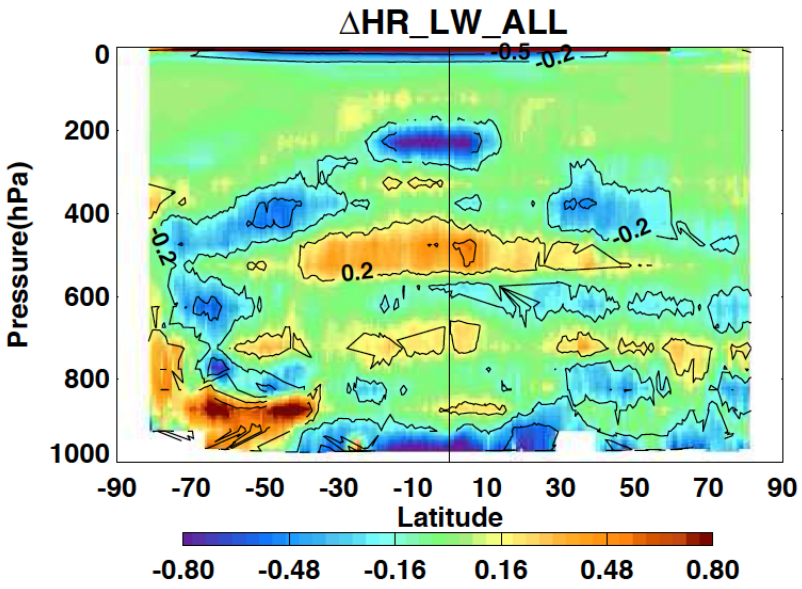
K day^{-1}

CCCM



K day^{-1}

SEN1deg - CCCM

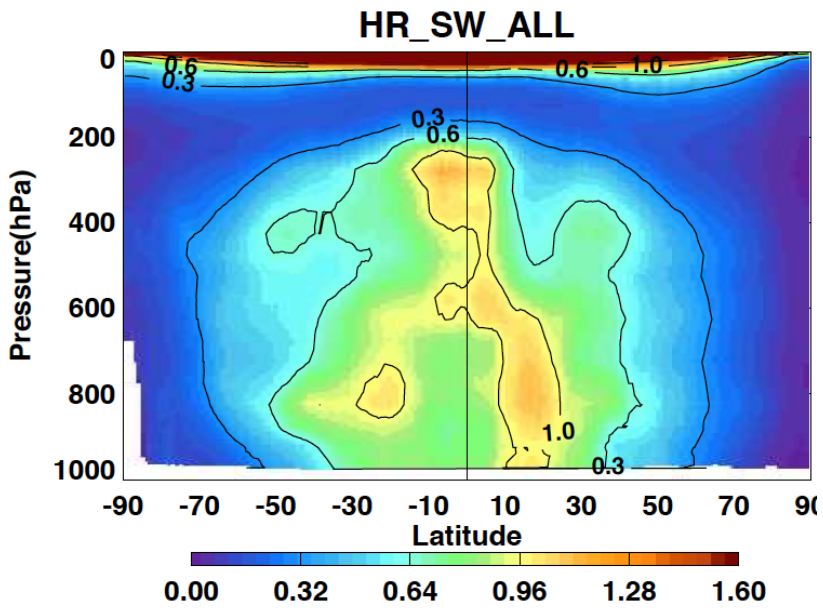


K day^{-1}

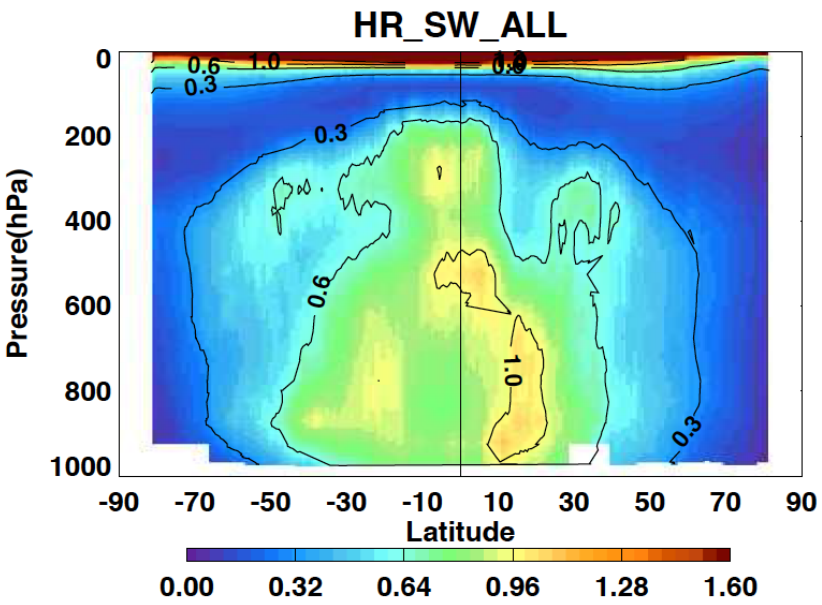
SYN uses 4 different cloud types: low (Surface to 700 hPa), mid-low (700 to 500 hPa), mid-high (500 to 300 hPa) and high (less than 300 hPa)

Shortwave heating rate, March 2011

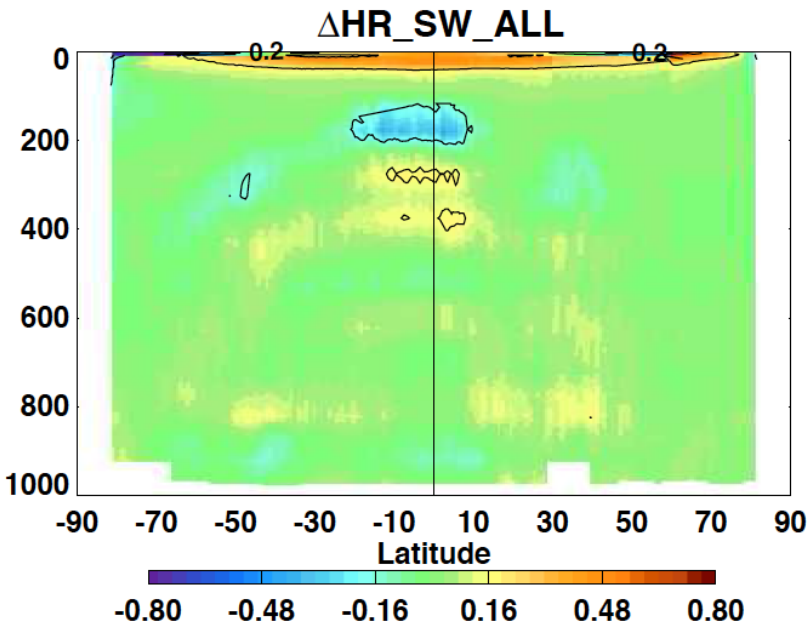
SYN1deg



CCCM

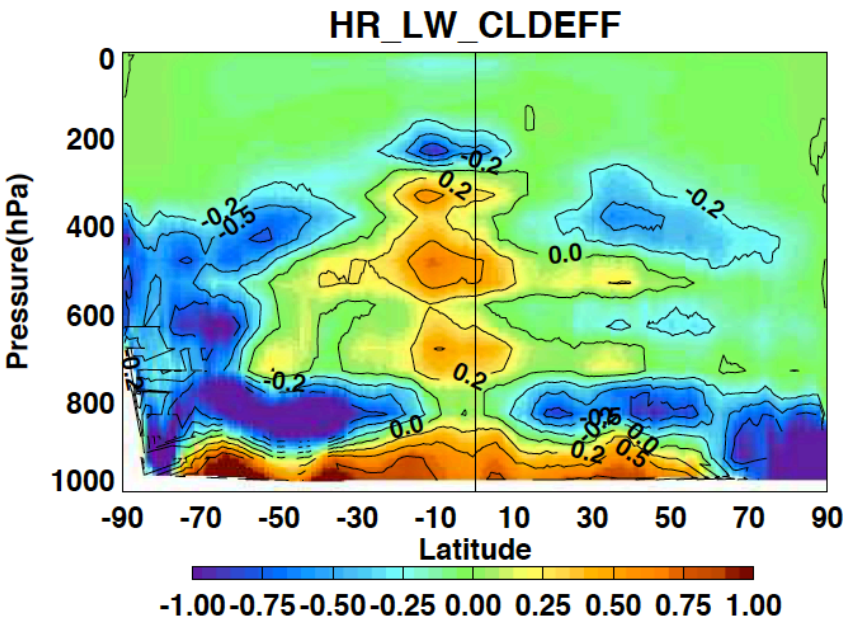


SEN1deg - CCCM

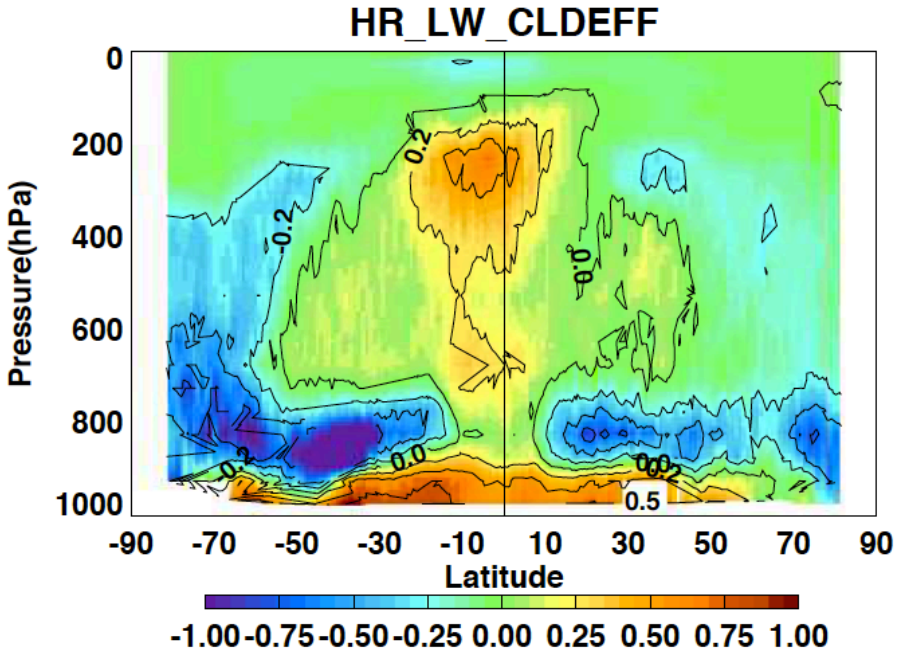


Cloud radiative effects (Feb. 2011)

SYN (passive only)



C3M (passive + active)



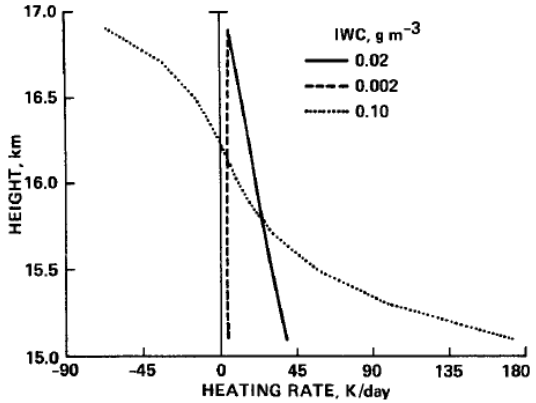


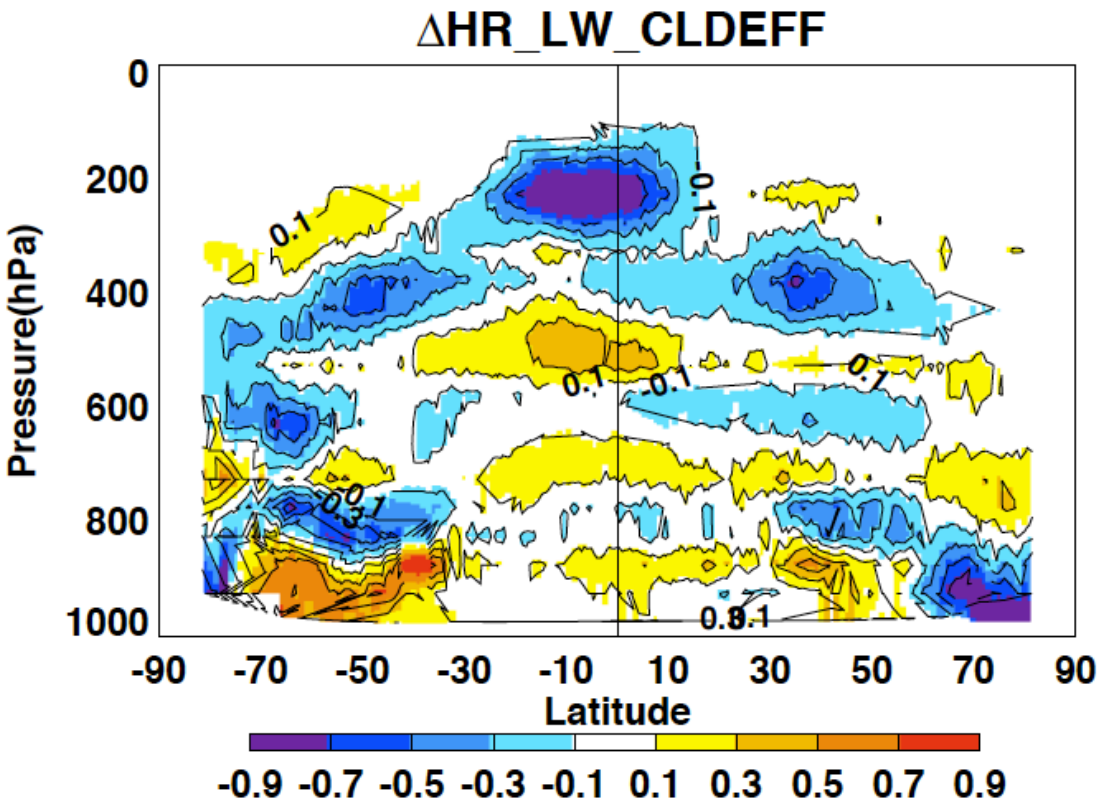
FIG. 6. In-cloud heating rates as a function of height for three constant ice water contents: 0.02 g m^{-3} (solid curve), 0.002 g m^{-3} (dashed), and 0.10 g m^{-3} (dotted). (Note the horizontal scale of this figure is substantially compressed relative to other figures.)

Ackerman et al. 1988

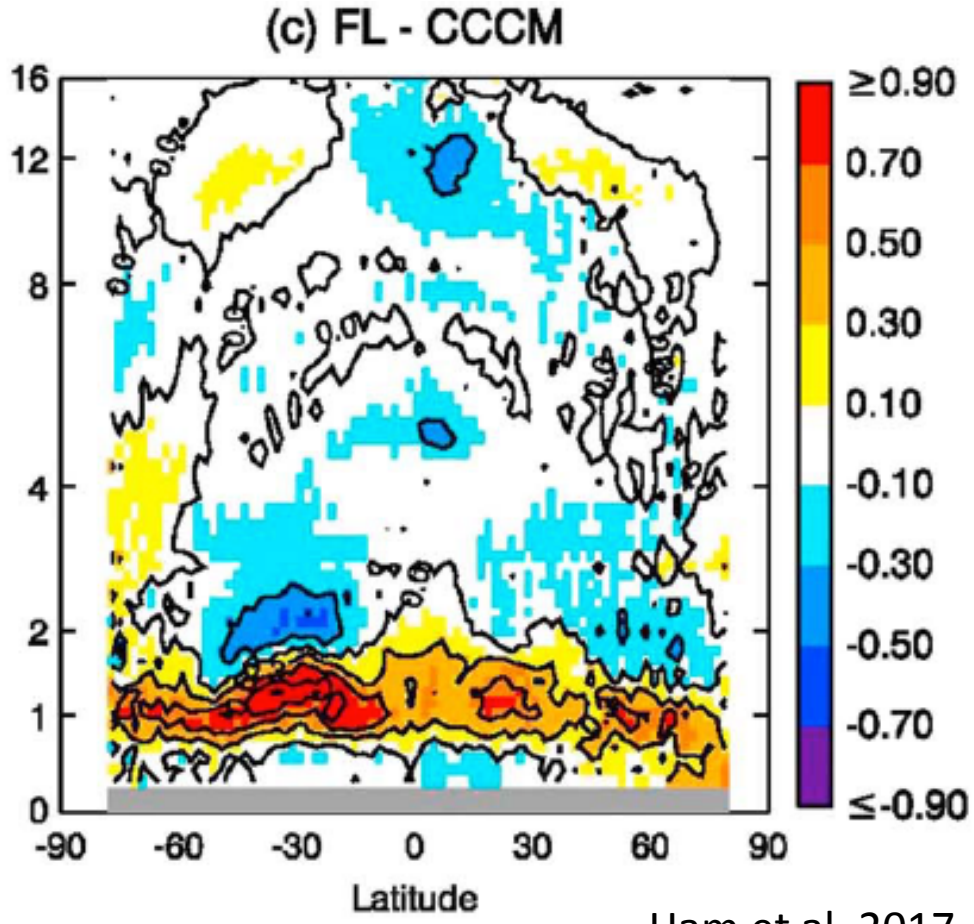
SYN heating rates have large cloud top cooling and the maximum of heating is too low.
Cloud extinction distributed in the atmospheric column when active sensors are used.
Cloud optical thickness for a given cloud layer is too large when only passive sensors are used.
As a consequence, cloud top cooling and cloud base warming is too large.
This is consistent with low bias of computed TOA longwave compared with CERES observations.
If we believe cloud top height and optical thickness, higher cloud base height might be causing the problem.

SYN, CCCM, FLXHR-LIDAR longwave cloud radiative effect

SYN- C3M for Feb. 2011



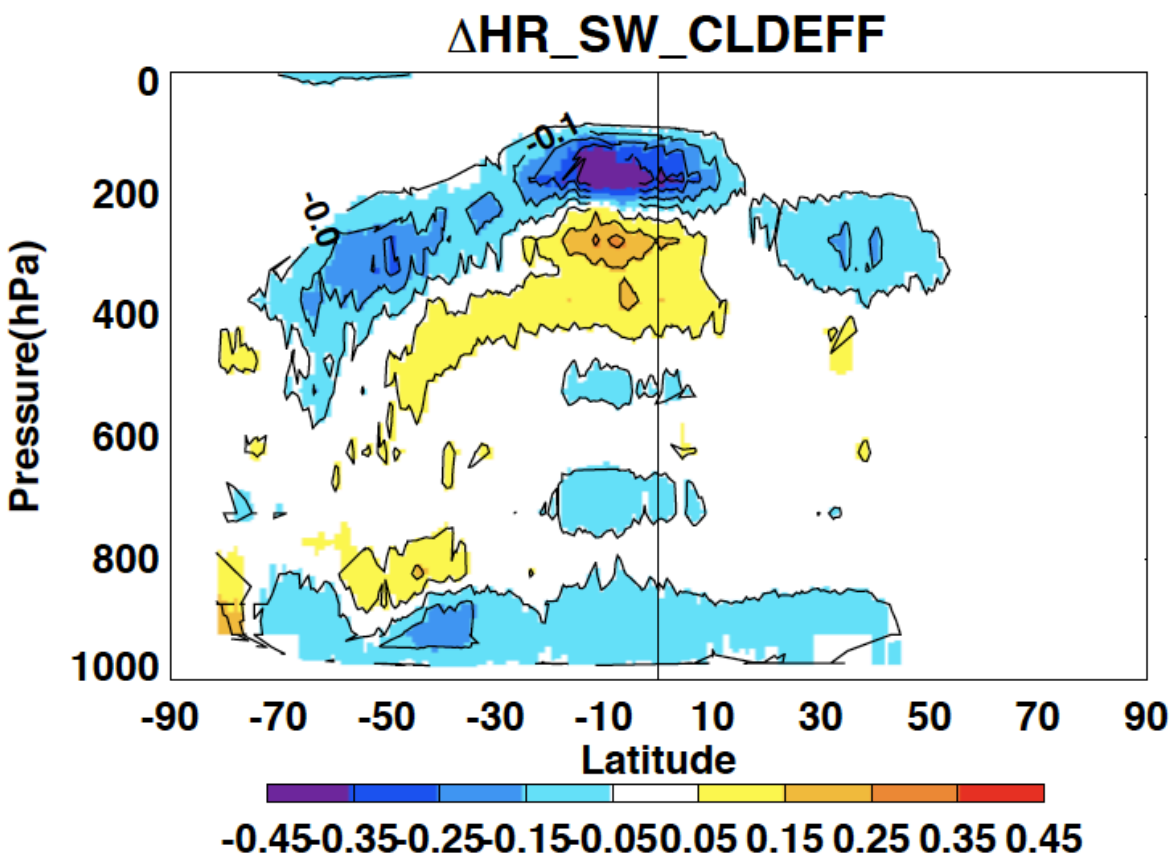
Difference (FLXHR-LIDAR - C3M) of LW heating rate from of seasonal months

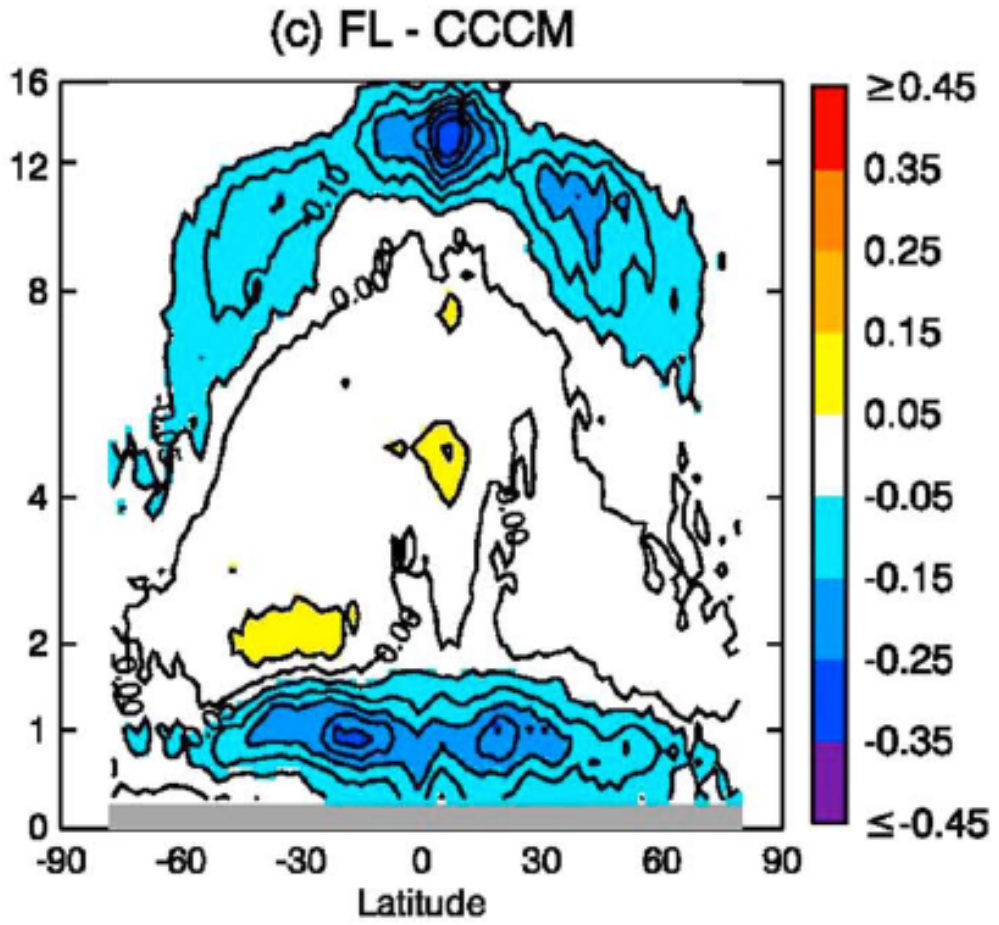


Ham et al. 2017

Error in SYN heating rate in middle to upper troposphere is significant.
Difference of low-level cloud heating rates is similar to the FLXHR-LIDAR CCCM difference

SYN, CCCM, FLXHR-LIDAR longwave cloud radiative effect





Ham et al. 2017

How MATCH aerosols are used in SARB

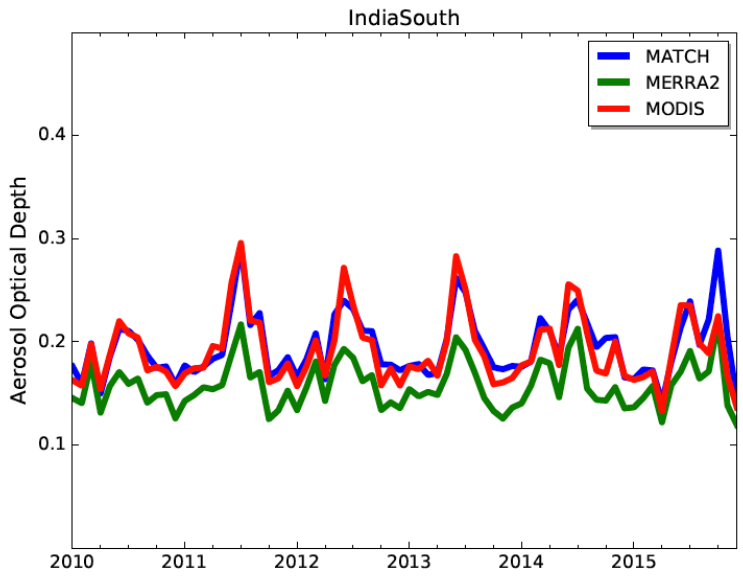
- MATCH assimilates MODIS aerosol optical thickness (hourly)
- MATCH provides vertical extinction profiles of 7 aerosol types
- Aerosol type determines optical property of aerosols
- David Fillmore 2013 CERES science team meeting
  - MATCH boundary layer AOD > CALIPSO AOD for most regions
  - Upper layer AOD ≈ CALIPSO AOD
  - MATCH absorption AOD ≫ MISR absorption AOD

Aerosol types

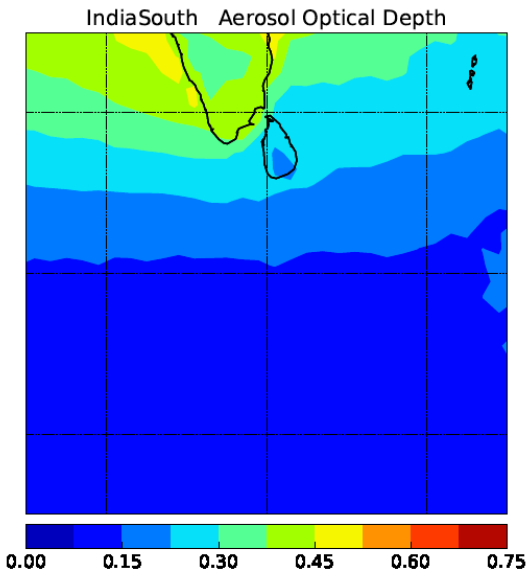
	Type	MATCH constituents	Reference
1	Small dust (<0.5 μm)	DSTQ01	Sinyuk et al. (2003)
2	Large dust (>0.5μm)	DSTQ02+DSTQ03+DSTQ04	Sinyuk et al. (2003)
3	Stratospheric	VOLC+stratosphere_SO4	OPAC suso
4	Sea salt	SSLT	D'Almedia (1991) maritime
5	Soot	BCPHI+BCPHO	OPAC soot
6	Soluble	OCPHI+tropospheric_SO4	OPAC waso
7	Insoluble	OCPHO	OPAC inso

MATCH vs. MERRA2 Southern India AOD 2010-2015

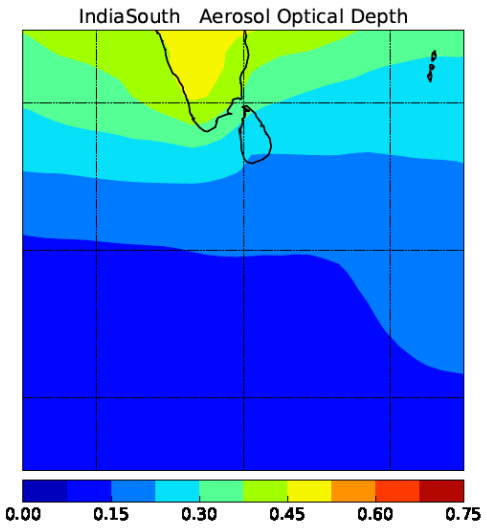
Southern India AOD 2010 - 2015



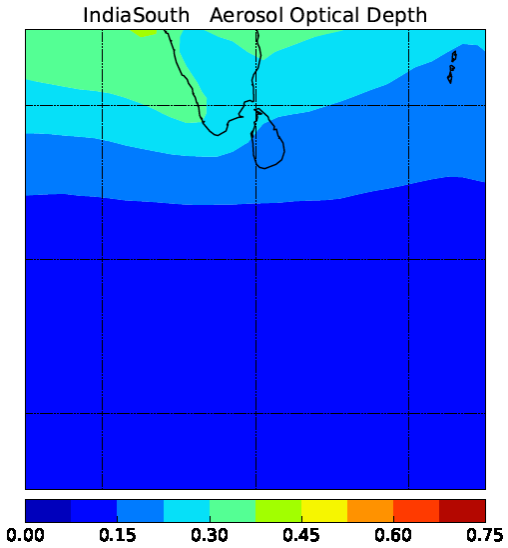
MODIS



MATCH



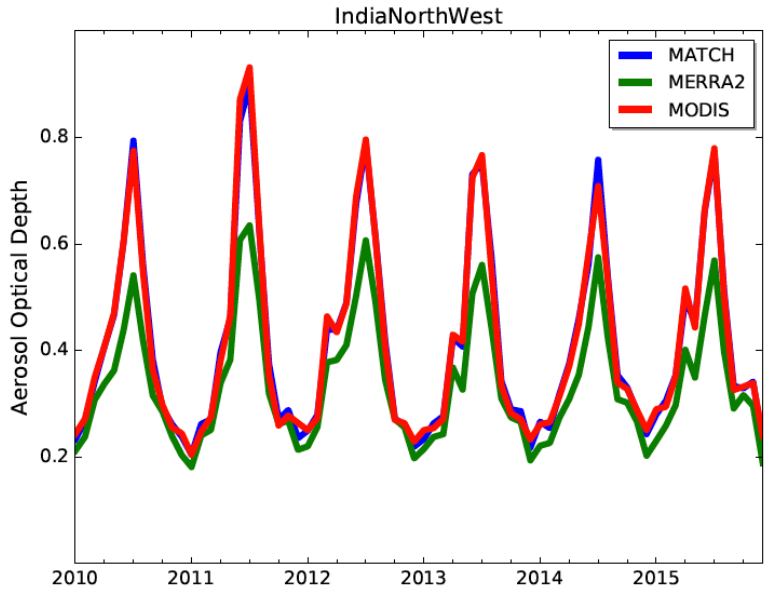
MERRA2



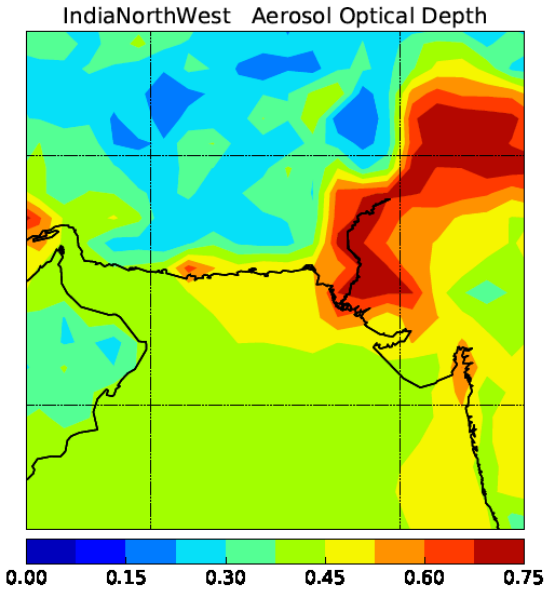
Fillmore 2016 CERES spring meeting

MATCH vs. MERRA2 North Western India AOD 2010-2015

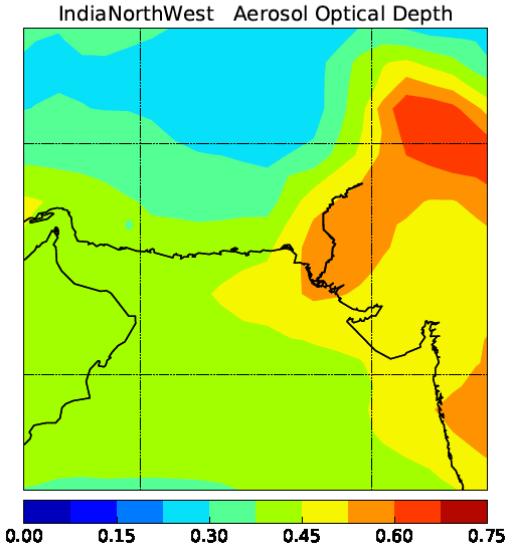
North Western India AOD 2010 - 2015



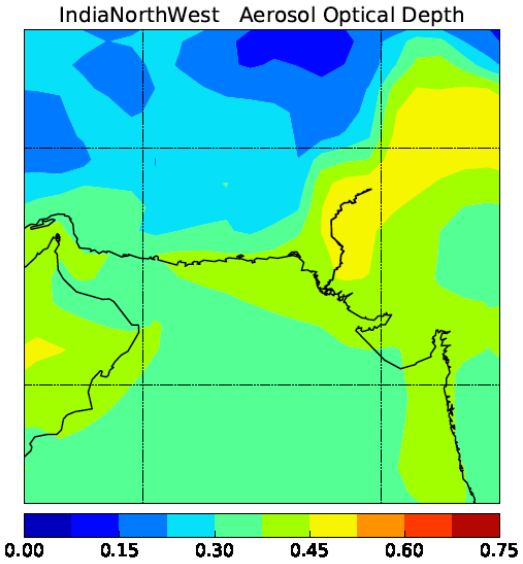
MODIS



MATCH

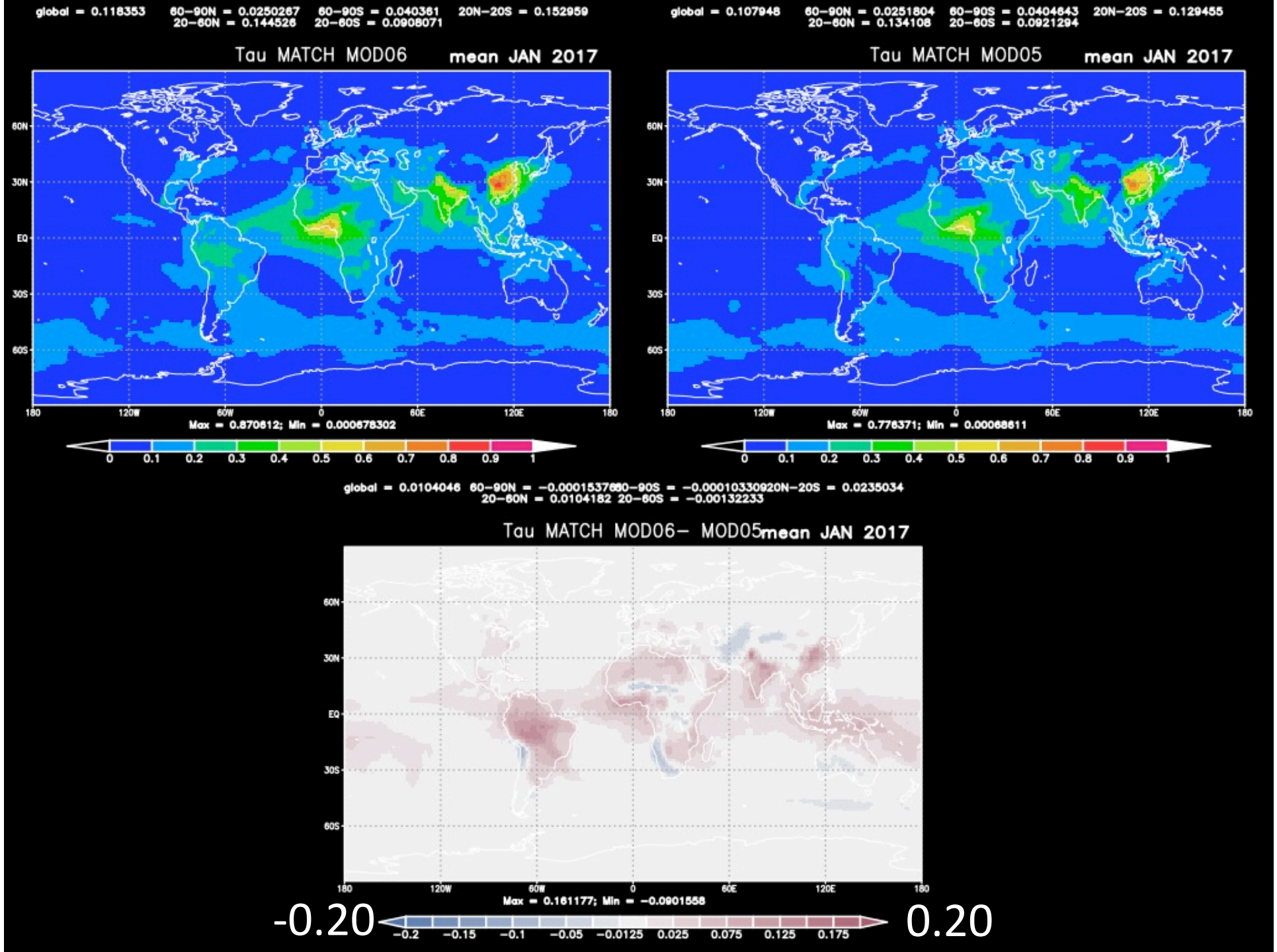


MERRA2



Collection 5 and collection 6 MODIS aerosols

- Monthly mean Match aerosol optical depth using Modis Collection 6 have generally larger optical depths in most regions
- Global mean is increased by 0.01 from 0.108 to 0.118 or ~10%
- Some regions have AOT increases of up to 0.15
- Aerosol increases decrease global mean sky surface shortwave flux by ~2Wm-2
- Some regions see decrease of ~ 15Wm-2
- Work done by Anne Wilber


global = 0.118353 60–90N = 0.0250267 60–90S = 0.040361 20N–20S = 0.152959
20–60N = 0.144526 20–60S = 0.0908071
Tau MATCH MOD06 mean JAN 2017
Max = 0.870612; Min = 0.000678302
global = 0.107948 60–90N = 0.0251804 60–90S = 0.0404643 20N–20S = 0.129455
20–60N = 0.134108 20–60S = 0.0921294
Tau MATCH MOD05 mean JAN 2017
Max = 0.776371; Min = 0.00068611
global = 0.0104046 60–90N = –0.0001537660–90S = –0.00010330920N–20S = 0.0235034
20–60N = 0.0104182 20–60S = –0.00132233
Tau MATCH MOD06– MOD05mean JAN 2017
Max = 0.161177; Min = –0.0901558
-0.20
0.20

Entropy production

Change of entropy S is the difference of entropy production by shortwave absorption and longwave emission to space

$$\frac{dS}{dt} = \dot{S}_a - \dot{S}_e + \dot{\Sigma}$$

Where Sa: entropy production by absorption of shortwave irradiance, Fsw_net / T
Se: entropy production by emission of longwave irradiance to space FLW_space / T
∑: entropy production by non-radiative processes (material entropy)

At a steady state (e.g. global annual mean) (Bannon and Lee 2017),

$$\dot{S}_e - \dot{S}_a = \dot{\Sigma}$$

90% of non radiative entropy production is due to vertical processes, such as convection (Lucarini et al. 2011)

Global annual mean entropy production

	SYNEd4 ($mWm^{-2} K^{-1}$)	Peixoto et al. (1991) ($mWm^{-2} K^{-1}$)	Stephens and O'Brien (1993) ($mWm^{-2} K^{-1}$)
TOA incoming SW (SYN80)	41	41.3	
TOA outgoing LW (SYN83)	1238*		1230*
Atm outgoing LW (SYN84)	827	854	
Sfc outgoing LW (SYN85)	115	71	
Atm absorbed SW (SYN87)	303	258	
Sfc absorbed SW (SYN88)	549	29.5	

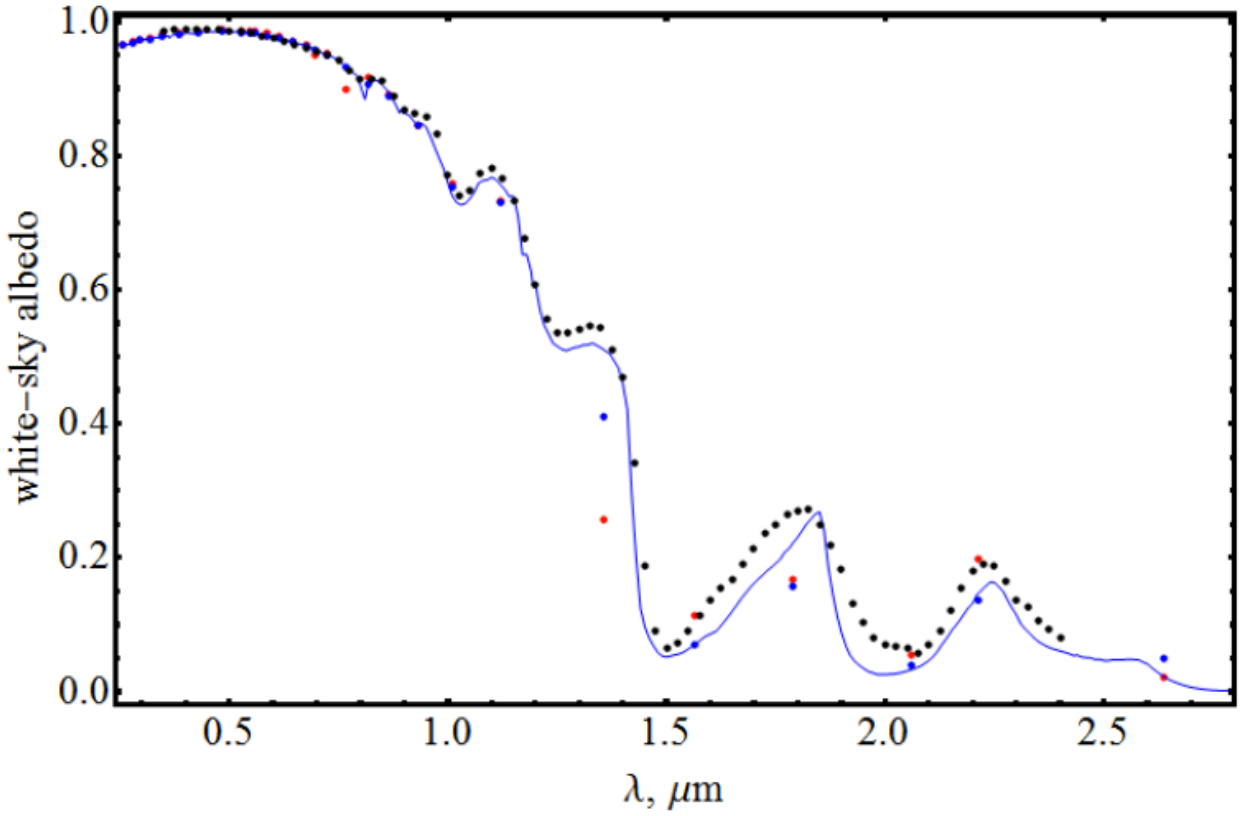
* Entropy flux, which includes (4/3) factor.

Entropy production by non-radiative processes = (827+115-303-549) = 90 $mWm^{-2}K^{-1}$

Mean of PCMDI/CMIP3 14 models with preindustrial scenario 55 $mWm^{-2} K^{-1}$ (Lucarini et al. 2011)

Development of snow spectral BRDF model

- Use observed snow BRDF at Dome-C
- Correction is applied based on theory in deriving black-sky albedo



Publications

- Ham, S, H., S. Kato, F. G. Rose, D. Winker, T. L'Ecuyer, G. G. Mace, D. Painemal, S. Sun-Mack, Y. Chen, and W. F. Miller, 2017: Cloud occurrence and cloud radiative effects (CREs) from CCCM and CloudSat Radar-Lidar Products, *J. Geophysic. Res*, 122, doi: 10.1002/2017JD026725.
- Scott, R. C., D. Lubin, A. M. Vogelmann, S. Kato, 2017: West Antarctic ice sheet cloud cover and surface radiation budget from NASA A-train satellites, J. Climate, 30, DOI: 10.1175/JCLI-D-16-0644.1
- Kassianov, E., J. Barnard, C. Flynn, L. Riihimaki, L. K. Berg, D. A. Rutan, 2017: Areal-Averaged Spectral Surface Albedo in an Atlantic Coastal Area: Estimation from Ground-Based Transmission, Atmosphere, 8, 123; doi:10.3390/atmos8070123
- Loeb, N. G., P. Yang, F. G. Rose, G. Hong, S. Sun-Mack, P. Minnis; S. Kato, S.-H. Ham, W. L. Smith, S. Hioki, G. Tang, 2017: Impact of Ice Cloud Microphysics on Satellite Cloud Retrievals and Broadband Flux Radiative Transfer Model Calculations, submitted.
- Kato, S., F. G. Rose, D. A. Rutan, T. J. Thorsen, N. G. Loeb, D. R. Doelling, X. Huang, W. L. Smith, and W. Su, 2017: Surface irradiacnes of Edition 4.0 Clouds and the Earth's Radiant Enrgy System (CERES) Energy Balanced and Filled (EBAF) data prodcut, *J. Climate*, Submitted.

Summary

- Edition 4 EBAF-surface and SYN1deg were released.
- Uncertainties in hourly mean surface downward shortwave irradiances is 42 Wm^{-2} and 46 Wm^{-2} for, respectively, ocean and land.
- Uncertainties in hourly mean surface downward longwave irradiances is 20 Wm^{-2} and 24 Wm^{-2} for, respectively, ocean and land.
- Ed4 SYN1deg Heating rate profiles are evaluated with C3M heating rates. Extinction coefficients of anvil and cirrus appear to be too large.